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A Real-Time BLE enabled ECG System for Remote Monitoring

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Abstract

A major requirement of ubiquitous healthcare systems consists in the provision of low power usage, battery operated devices that are used in long term patient monitoring. Thus far, researchers have tried to adapt various short range technologies such as IEEE802.15.4, classical Bluetooth etc., to achieve this goal. The IEEE802.15.4 was, by excellence, widely deployed because of its low power and its security features compared to technologies such as the classical Bluetooth. However, the Bluetooth Special Interest group has recently announced Bluetooth 4.0 with low energy technology (BLE) for low power personal area networked devices, which offers more compelling features in various aspects when compared to IEEE802.15.4. This makes its evaluation for healthcare applications an urgently needed endeavour. In this paper, we present a BLE-based remote health monitoring system in which we have interfaced an ECG simulator directly to a BLE enabled CC2540 wireless sensor node (a system-on-chip (SoC) for *Bluetooth* low energy applications, from Texas Instruments). The node acts as a slave to the Master BLE device. In our system, we have used a BLE112 module (from Bluegiga) as a slave node while for the master we have used a BLE USB dongle connected to a PC in order to manage data received from the sensor node. A server application running on the PC uses a TCP-based connection over the network interface in order to enable remote monitoring. Any remote client can connect to the server and receives live updates from the sensor node. We have developed a LabVIEW based TCP client application to provide this functionality. An ECG simulator was used to generate ECG signals for different heartbeat rates that were sent through the BLE enabled network. The waveforms received at remote station using the developed system were found to conform exactly to those captured using a high resolution oscilloscope.

Keywords: WBAN, U-Healthcare, BLE, Wireless, ECG

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1. Introduction

Ubiquitous healthcare system is an important paradigm that is expected to meet the challenges related to growing population, high healthcare expenses and chronic diseases as it enables the medical practitioners to remotely monitor the patient's physiological data in real-time and provide a suitable feedback. A variety of mobile and ubiquitous healthcare solutions that were proposed for real time monitoring of ECG [1,2] have been presented using technologies such as IEEE802.15.4 [3] and the classical Bluetooth [4]. Among those developed solutions IEEE802.15.4 served better the purpose by virtue of its attractive security and low energy consumption features when compared to classical Bluetooth. However the Bluetooth Special Interest group (SIG) has recently announced a new standard for low power personal area network devices named Bluetooth Low Energy (BLE) also referred as Bluetooth version 4.0 [5]. Bluetooth 4.0 wireless technology is developed to provide features such as low-power, low latency, short-range and small-coin battery cell operation.

It provides a maximum data rate of around 1Mbps and supports a range of about 100 meters, triggering its use for a wide range of applications with small form factors in industries such as healthcare, fitness, security and home entertainment. From above facts, it seems obvious that BLE offers more fascinating features when compared to IEEE802.15.4. However its performance for such applications still needs to be determined. A brief comparison of BLE with IEEE802.15.4 and Zigbee is shown in Table 1.

Table 1. Comparison of BLE and IEEE802.15.4

Features/Technology	Zigbee/IEEE 802.15.4/6LowPAN	Bluetooth Low Energy (BLE)
Radio Frequency	868 /915MHz, 2.4GHz	2.4GHz
RF Data Rate	250Kbps	1Mbps
Distance	10-200 meters	10 to 100m (Typical)
Peak Current Consumptions	< 15mA	< 15mA
Application Throughput	< 0.1 Mbps	0.2Mbps
Network Topology	Star or Mesh	Star-bus
Robustness	DSSS, Uses 16 Channels in ISM (2.4GHz) band only.	Adaptive Frequency Hopping
Security	128b AES and application layer user defined	128b AES and application layer user defined

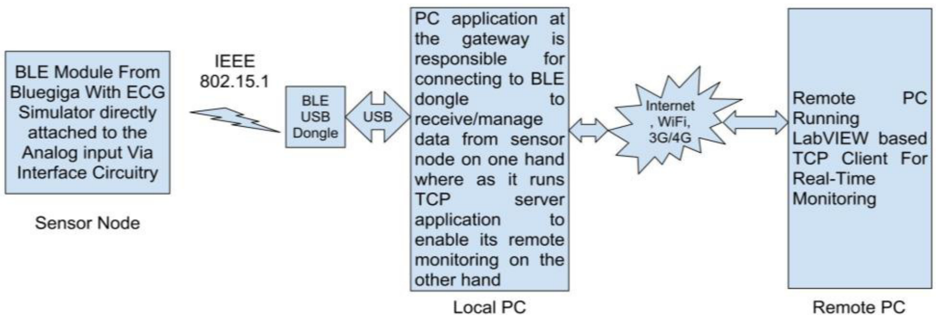


Fig. 1. Block Diagram of Developed System

Figure 1 describes the block diagram of the developed system. In Section 2, we will give an overview of

BLE technology. In Section 3 we will describe proposed system design and will illustrate about the sensor node programming. Section 4 focuses on the gateway application that is used to receive, save and manage data from the BLE node via USB dongle on one hand where as it listens for the TCP client from remote location on the other end. Section 5 describes the remote TCP-based client application that was developed using the graphical software LabVIEW [6] for real-time monitoring of the ECG data. In addition, the ECG results captured using high resolution scope were compared with the ones obtained using the remote LabVIEW-based TCP client application for conformity and were found in close agreement. Finally, we conclude the paper.

2. BLE Overview

In this section, we will first give some basic introduction related to Bluetooth. A typical Bluetooth stack is shown in Fig. 2 below. The stack is divided into two main parts that are named Controller and Host. The Controller part that is generally implemented in the form of a system-on-chip is usually integrated with Bluetooth radio and refers to the lower Layers of the stack responsible for handling physical layer transmission and its associated timings and encoding. On the other hand, the upper layers at the host applications (which usually have relaxed timings) include APIs and profiles. This part usually runs on a separate processor together with the user application.

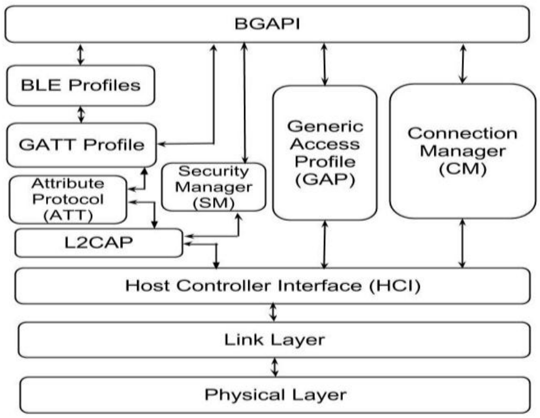


Fig. 2. Block Diagram of BLE[4] Stack

A BLE stack consists of the Physical Layer that operates at the frequency of 2.4 GHz and makes the use of around 40 channels that are 2 MHz apart. There are 2 types of channels for BLE devices: advertising channels and data channels. Advertising channels are used for advertisements related activities, device discovery, broadcast and connection establishment, while data channels are used for transferring data between devices. In BLE, there exists an 'advertiser' that transmits advertising packets through advertising channels at precise time intervals referred to as advertising events, and a 'scanner' that acts to receive data using the advertising channels. BLE devices first need to connect to each other before they begin a reliable two-way data communication. The connection between the two devices is an asymmetric procedure in which the advertiser transmits advertisements packets through advertising channels, whereas the other device that is the initiator that listens for these packets. Upon receiving those packets the initiator transmits a connection request message to the advertising device which allows a connection to be established, thus enabling a point to point link between two.

The Link Layer in BLE defines the devices as Master and Slave, which act as initiator and advertiser, respectively, during connection establishment. A Master can connect to as many slaves as possible, thus forming a star network. In basic routine operation slaves get into sleep mode and turn themselves on, periodically, to listen for any packets from the Master. It is the Master, usually, who determines the sleep/wake-up periods of the slaves.

BLE uses a lighter version of the Logical link control and adaptation protocol (L2CAP) that was defined for the classic Bluetooth. The main task of the L2CAP here is maintained to take care of multiplexing data from the three higher layer protocols, Attribute Protocol (ATT), the Security Manager Protocol (SMP) and Link Layer control signaling, on top of a Link Layer connection. Here the L2CAP offers a best-effort endeavour to get the data of these services transmitted to the next hop without using retransmission and flow control mechanisms available in earlier Bluetooth versions. Another feature that is dropped from earlier Bluetooth version in the BLE L2CAP is Segmentation and reassembly under the assumption that higher layer protocols provide PDUs that fit into the maximum L2CAP payload size, which is equal to 23 bytes in BLE [7-8].

The server client role is determined by the Generic Attribute Profile (GATT) and is independent of the Master/Slave configuration. The server attributes can be requested by the client by sending an attribute request, moreover the server can also send to the client two types of unsolicited messages that contain attributes which include 1) notifications and 2) indications. In order to enable security, the security manager enables various security modes for BLE. The Generic Access Profile (GAP) runs at the higher level and defines the 4 roles on the underlying controller which include *Broadcaster*, *Observer*, *Peripheral* and *Central*. In Broadcaster mode data is *broadcast* using the advertisement channels, which does not allow connections with other devices. *Observer* role allows receiving data from *broadcaster*, whereas the *Central* role is used for devices that are in charge of initiating and managing multiple connections. The peripheral role is used for simple devices that use single connection with a device in central role.

3. Proposed System Design

In our system, for sensor nodes (i.e., Slaves) we have used a BLE enabled wireless module (the BLE112) from Bluegiga [9] which is based on the CC2540 module from Texas Instrument [10]. Using the BLE112 gives immediate benefits such as it can host the complete end user applications without the use of an external host or microcontroller and provides host interfaces such as UART in applications where external host is required. In addition, it provides ultra low power consumption of 27mA at 0dbm, it has a dimension of only 12 x 18 x 2.3mm and it allows slave connections for up to 4 connections in Master mode. Furthermore, the BLE112 [9] kit comes with a complete software development guide for both application and profile development and provides Digital and Analog I/O's and peripherals for direct interfacing with the sensors and allows coin cell operation.

In our setup, we have used a single standalone chip without any external host processor as slave node, in which a complete BLE profile stack and our developed user application running on the single BLE112 wireless module using BGscript software from Bluegiga[9] were deployed. The block diagram of this is shown in Fig. 3a.

The slave usually acts as an advertiser which keeps on advertising itself periodically until a connection is established. The advertiser's advertisements messages are generally destined for a master that is listening to any advertising device in order to connect to it. The communication between the master and the slave relies on the GATT, which describes service group, roles and general behaviours. Services are collection of characteristics and relationships to other services that encapsulate the behaviour or the device including hierarchy of services, characteristics and attributes used in the attributes server. Figure 3b describes the relationship between the profile, characteristics and service in our case.

We did program the BLE node using the BGscript software from Bluegiga. A BGscript project consists of .xml and .BGS files. XML files are used for the definition of the hardware configuration of the BLE module and for the definition of the profile and database. BGS files on the other hand are used for BGscript that is usually responsible for reading the data from the different interfaces of the module (such as I2C, SPI, UART e.t.c) and writing them to the profile data base whenever a certain event happens. Most of the code in this file is event driven that happens as a result of function call that can either be called by the client who requests the read operation from the server or may happen because of timer expiration or ADC read event or any other event. When the project gets compiled it transforms the code into a binary .out file as an image which is then burnt into the BLE module. In our project there was hardware.xml for hardware control, GATT.xml file that contains information regarding profile and service description related to the profile and project.xml file that contains information related to the files that will be compiled.

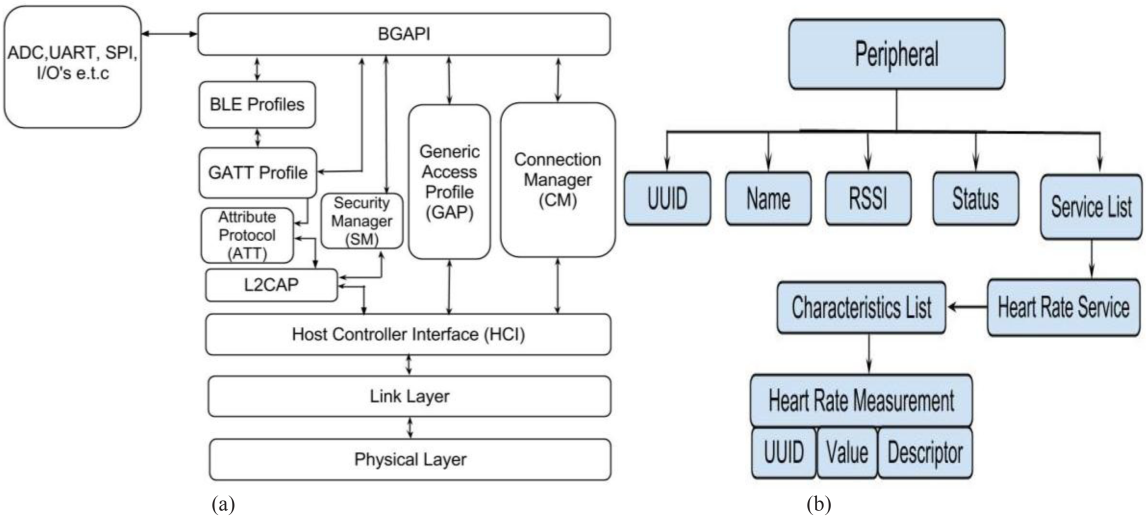


Fig. 3. (a) BGscript [9] application block Diagram handling data between peripherals and BLE stack using BGAPI; (b) The hierarchy of our developed Peripheral

4. Experiments and Evaluation

4.1. Gateway Application

On the PC side a BLE USB dongle was used and was acting as the Master to the node. The firmware inside the USB dongle has also been provided by the Bluegiga where the PC acts as the external host to the BLE USB dongle. The USB dongle when plugged into the PC is detected as a COM port. BGAPI guide has been provided by the Bluegiga in order to control and send command to the dongle in order to connect to the sensor node that is broadcasting advertisement messages. The BGAPI programming is done using simple C call back functions. Fig. 4a gives the block diagram of the gateway application and illustrates how the PC application interacts with the USB dongle using Bluegiga BGLib that usually runs on an external host.

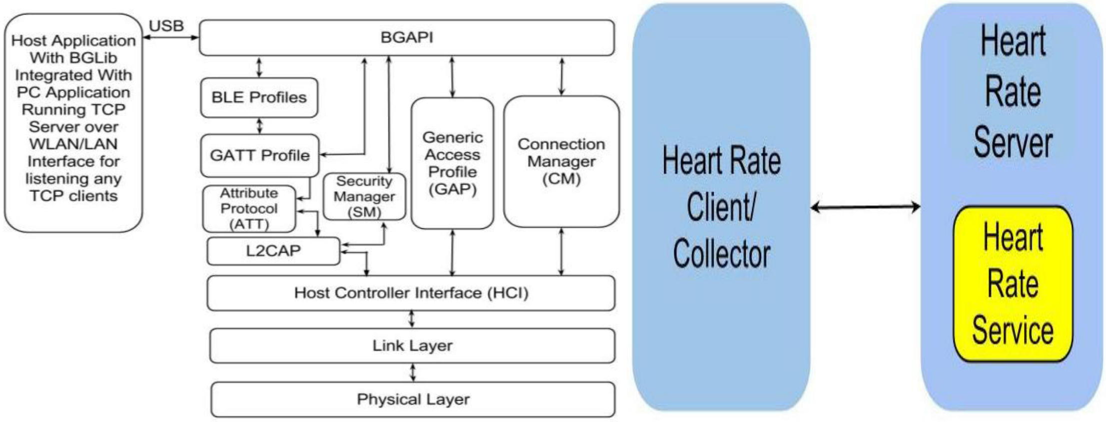


Fig. 4 (a) BLE Stack overview; (b) Heart rate Profile Role

We have written an application on the Gateway in which we have used the BGLib on the PC connected to BLE USB dongle as host. First we connected to the device using its broadcast messages and then we sent commands to discover its services. The sensor node, which in our case is a server, exposes one service only that is the Heart Rate sensor measurement. Fig. 4b shows the services that the server exposes.

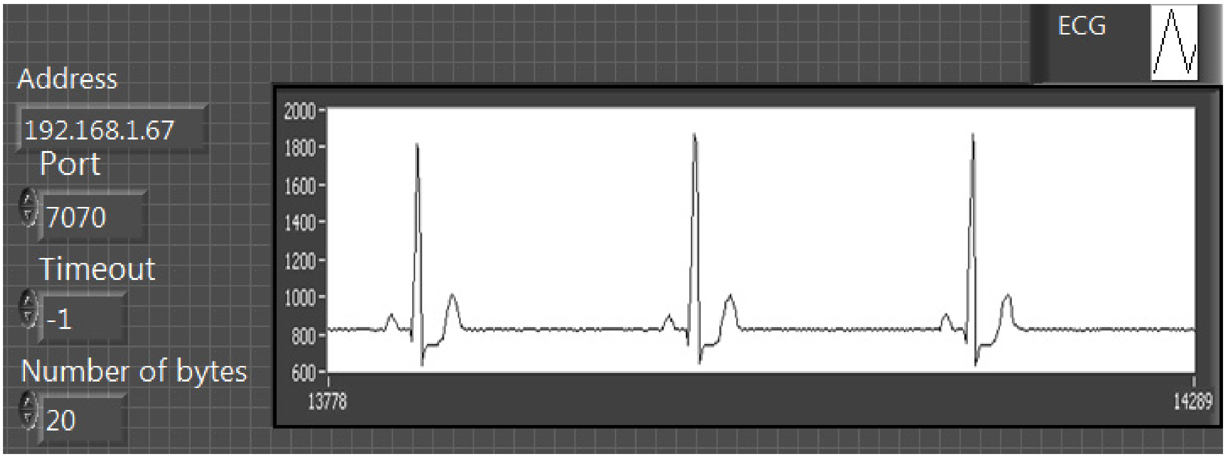
4.2. Remote Application

The data is reported in the form of characteristics measurements. When the notification configuration of the characteristic is written to 1, the receiver starts receiving the data from the node. In our case the node gathers 10 samples of the ADC data and writes them to the GATT database. The sensor node Analog ADC is interfaced with the ECG simulator in order to evaluate the BLE transmission technology for various ECG rates. Once the Gateway application starts receiving the data from the node it pushes the same data to the file for record. Moreover it runs a TCP connection-based server which listens to any remote TCP clients over the WiFi/LAN interface. As soon as the TCP client tries to connect to the server the remote client starts receiving the live updates of the ECG data.

5. ECG Real Time Remote Data

Fig. 5 (a) shows a snapshot of LabVIEW application running on the remote PC and receiving the Real-time data of the ECG that is forwarded to it by the TCP server application running at the gateway.

In Fig. 5(a) address field represents the address of the gateway PC whereas the port represents the port on which the TCP server at the gateway is listening. In order to evaluate the network and system performance at different ECG rates, an ECG simulator with was integrated in the system. Figure 5(b) compares the remote ECG curves received through BLE to those captured locally by a high-resolution scope directly connected to the ECG simulator device. The curves are shown for ECG rates of 30, 90 and 180 bps. Figure 5(b) exhibits close matching between the curves received over the BLE connection to those received locally. From the above Fig. 5(b) it is evident that we can use this system for real-time monitoring of the ECG or other various similar bio-signals. The system is operable using a single coin cell which fosters wear-ability.



(a)

(b)

Fig. 5 (a) A Snapshot of LabVIEW TCP Client Receiving the ECG data at Remote Location (b) A comparison between Scope Captured and LabVIEW Captured data for various ECG rates

6. Conclusion

A real-time BLE-enabled remote health monitoring system was developed. The system is able to accurately transmit ECG data to a local computer. Also, the system enables real-time remote monitoring of health-related ECG parameter, via TCP clients like LabVIEW. The main advantage of using this system is that it enables monitoring using one single chip without the use of any external host processor. This uniquely supports low-power monitoring as compared to other solutions such as IEEE802.15.4 motes which requires the use of external microcontroller. Moreover, the current BLE module is very convenient from the wearability point of view since it is quite small and operable using a single coin battery. The results of the scope captured waveforms and those captured using BLE on LabVIEW at the remote station revealed close matching. Hence, it can be concluded that this technology has a great potential for next generation u-healthcare applications.

Acknowledgements

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